Fundamental physics

Pierre Binétruy

Deepest problem facing us: reconciling two surprisingly successful theories

- quantum theory describing the microscopic world through the Standard Model
- general relativity as a theory of gravity describing the Universe in its large (largest?) dimensions

Reconciling the two theories: where do they collide?

- issue of vacuum energy (vacuum ↔ quantum theory
  absolute energy ↔ expansion ↔ GR)

infamous cosmoloical constant problem

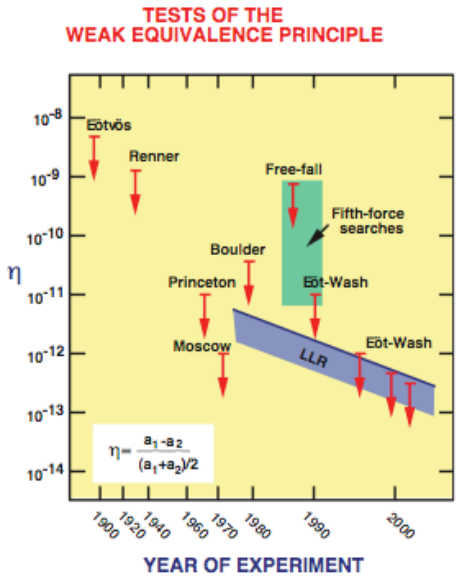
- issue of Lorentz violations

e.g. non-commutativity $[x_\mu, x_\nu] = \frac{i}{\Lambda_{NC}^2}\Theta_{\mu\nu}$ *associated with quantum gravity*

- violations of equivalence principle

Einstein's equivalence principle:

η
differential acceleration



- Weak Equivalence Principle: universality of free fall

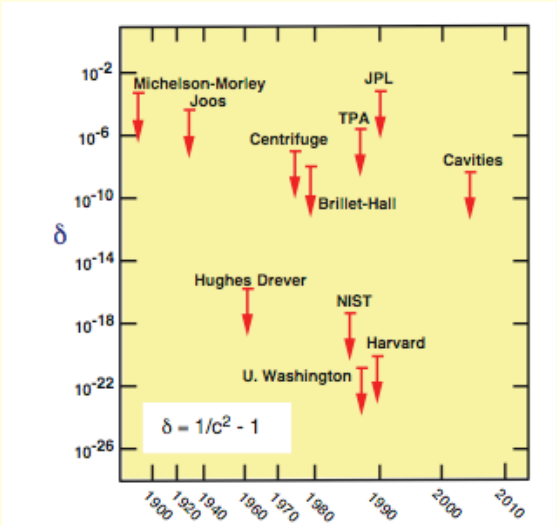
violation

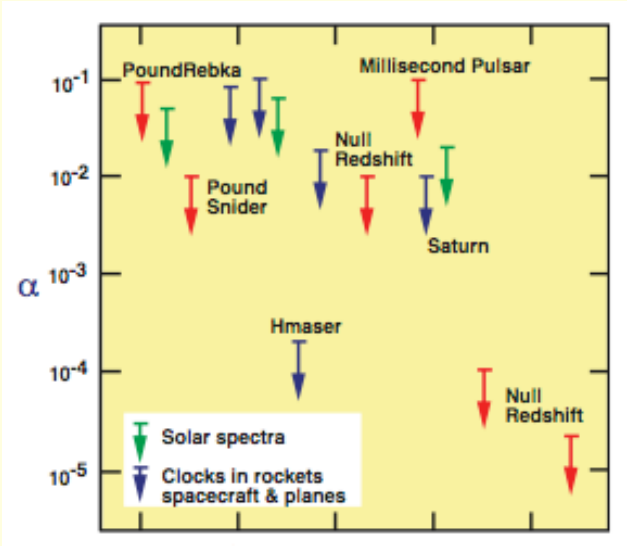
- Local Lorentz Invariance : independence on the velocity of the freely falling reference frame for nongravitational experiments

$c^2 \neq 1$

- Local Position Invariance : independence on the location in time and space where the nongravitational experiment is performed

nonconstancy of csts





grav. redshift

$\delta = |c^{-2}-1|$

$\Delta\nu/\nu=(1+\alpha)\Delta U/c^2$

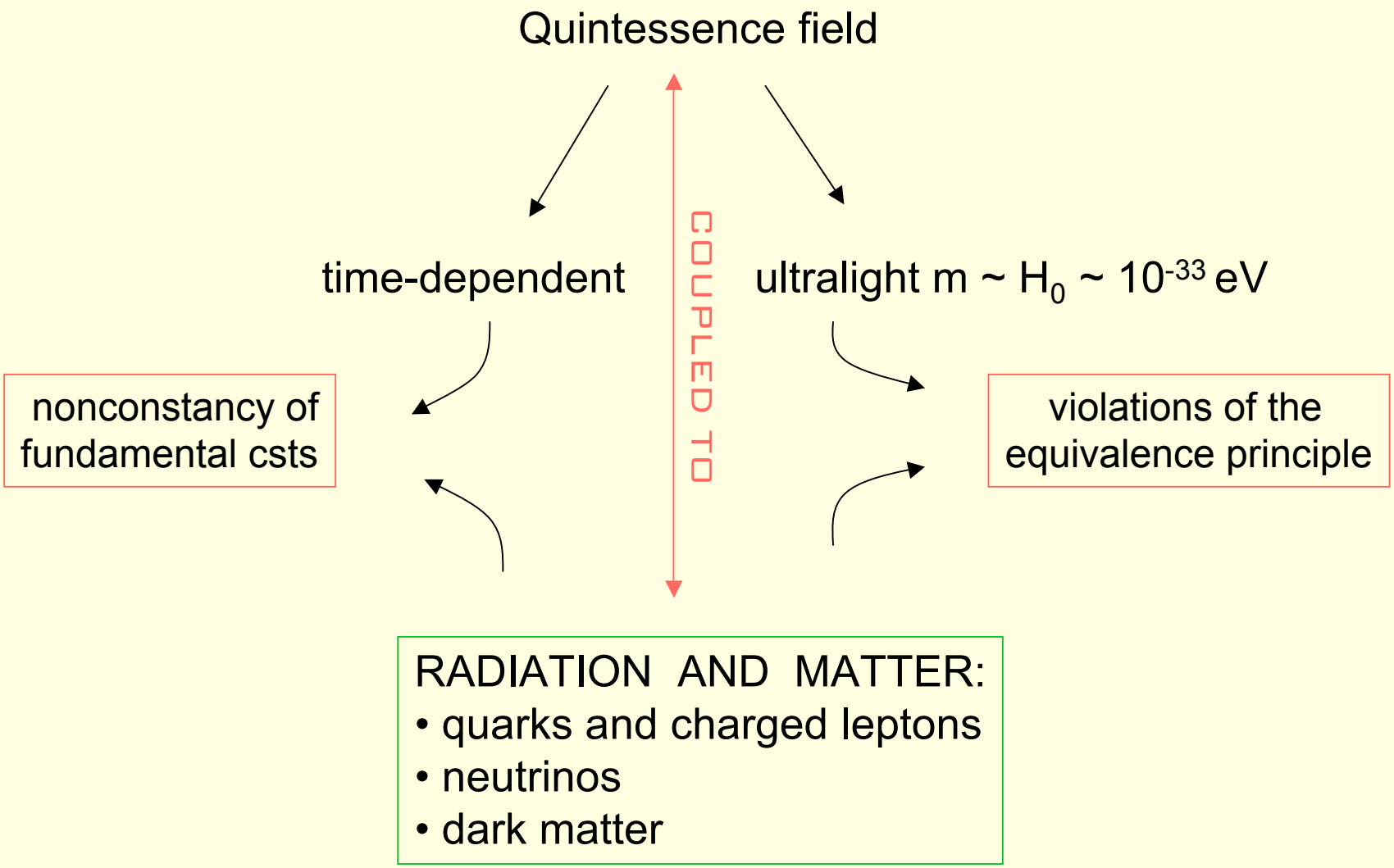
Two remarks:

1. The role of supersymmery

Global supersymmetry is the only known symmetry which sets the vacuum energy to zero.

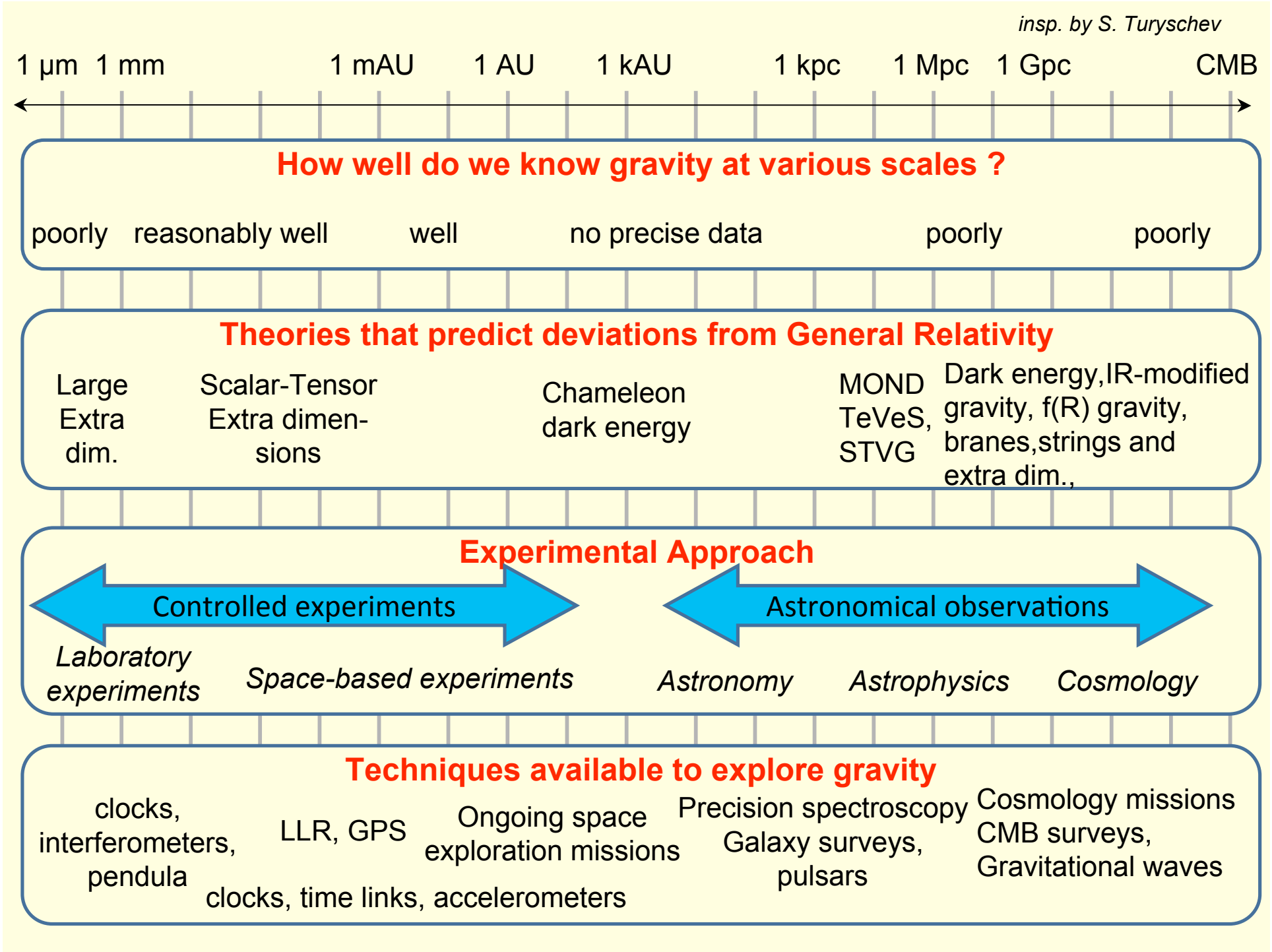
Supersymmetry is the only known symmetry which controls the largest violations of Lorentz invariance (up to dim. 5 operators in the SM).

2. Dark energy and equivalence principle

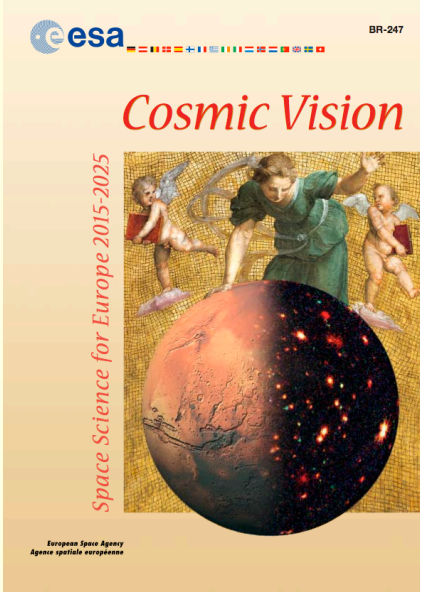


At which level do we expect violations of the equivalence principle?

At which level do we expect deviations from w=-1?

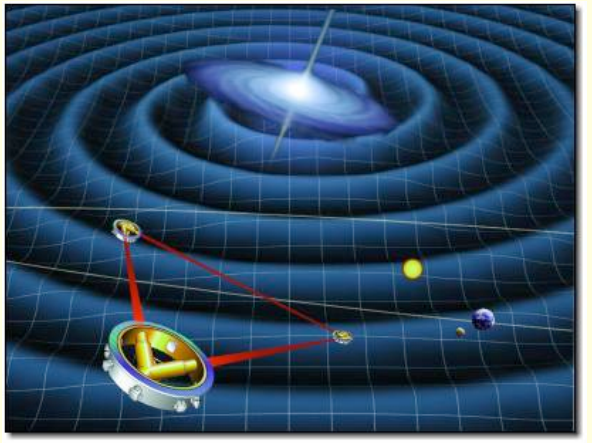

insp. by S. Turyschev
1 μm
1 mm
1 mAU
1 AU
1 kAU
1 kpc
1 Mpc
1 Gpc
CMB
How well do we know gravity at various scales ?
poorly
reasonably well
well
no precise data
poorly
poorly
Theories that predict deviations from General Relativity
Large Extra dim.
Scalar-Tensor Extra dimen-sions
Chameleon dark energy
MOND TeVeS, STVG
Dark energy,IR-modified gravity, f(R) gravity, branes,strings and extra dim.,
Experimental Approach
Controlled experiments
Astronomical observations
Laboratory experiments
Space-based experiments
Astronomy
Astrophysics
Cosmology
Techniques available to explore gravity
clocks, interferometers, pendula
LLR, GPS
Ongoing space exploration missions
clocks, time links, accelerometers
Precision spectroscopy Galaxy surveys, pulsars
Cosmology missions CMB surveys, Gravitational waves

A coherent space program for fundamental physics in Europe



ESA large missions:

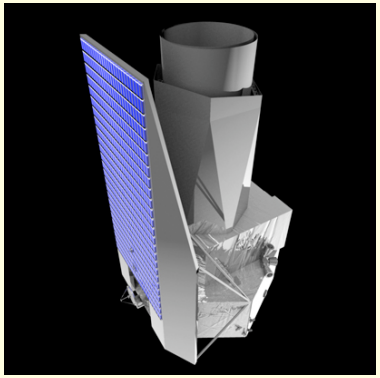
LISAPathfinder 2014?
approved



LISA 2022
selection in 2014?

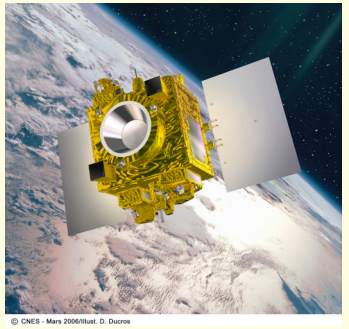
ESA medium missions :

EUCLID
2018-2020?

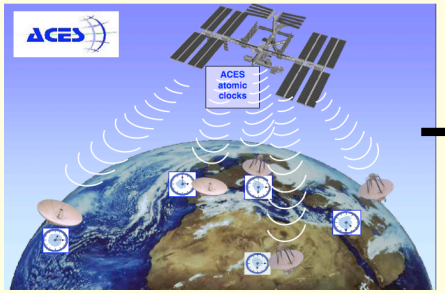


Selection to M2 slot in October 2011

CNES :



MICROSCOPE 2014
Test of equivalence principle

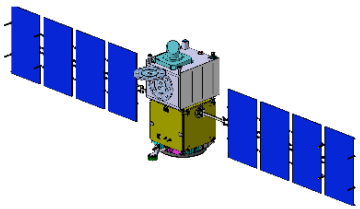


ACES 2015

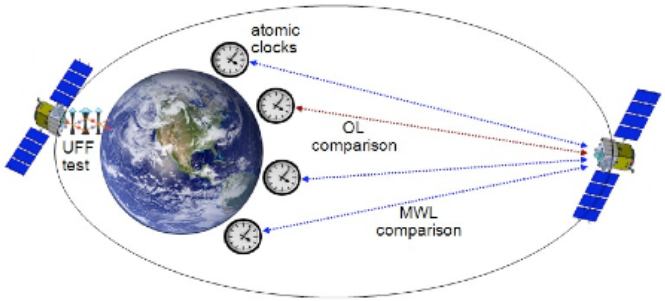
STE-QUEST

(Space-Time Explorer and Quantum Equivalence Principle Space Test)

A class M mission proposal for Cosmic Vision 2015-2025



2020?



Some potential questions for discussion:

- Do we have a complete theory to test dark energy ?

i.e. a realistic theory (not just an ad hoc model) fulfilling all the existing constraints especially coming from tests of fundamental laws such as the equivalence principle

- Vacuum energy: do we understand the connection between inflation and dark energy?

- Is dark energy a « complex physical phenomenon »?

so far described basically by 2 numbers: Ω_Λ and w_0

- How to test the nature of spacetime in lab experiments ?

Fermilab holometer

- What is the future of the field of ultra-high energy cosmic rays ?

High energy physics or astrophysics?

- What is the US cosmic frontier strategy on international collaboration ?

dark energy (numerous projects on ground, WFIRST status), dark matter, DUSEL status, ultra-high energy cosmic rays, …